

CHAPTER 47

SIZE AND SHAPE CHARACTERISTICS OF AMPHIBOLE ASBESTOS (AMOSITE) AND AMPHIBOLE CLEAVAGE FRAGMENTS (ACTINOLITE, CUMMINGTONITE) COLLECTED ON OCCUPATIONAL AIR MONITORING FILTERS

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ABSTRACT

The objective of this study by the Bureau of Mines (BOM) was to determine if particle populations from asbestiform and nonasbestiform mineral sources can be distinguished through least-squares regression analyses using the relationship:

$$\log_{10} \text{ width} = F \log_{10} \text{ length} + b$$

where F = fibrosity index, the slope of the regression line
 b = intercept on the \log_{10} width axis

Amphibole particles on air monitoring filters from three mining and two industrial sites were characterized by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) analysis. The data are evaluated using particle length and width summary statistics and compared with analyses by linear regression.

Conclusions based on comparison of data manipulation using these two techniques follow: The mining site particle populations are morphologically

similar, the industrial site particle populations are morphologically similar, and size and shape characteristics of mining site populations are statistically different from those of the industrial sites. Determination of either an asbestos or a nonasbestos source of amphiboles using linear regression techniques on data obtained from examination of air monitoring filters is a potential application of this technique.

INTRODUCTION

The purpose of this study by the BOM Particulate Mineralogy Unit, was to determine if particle populations collected on air monitoring filters from asbestiform and nonasbestiform amphibole mineral sources can be distinguished by the application of least-squares regression analysis to size and shape characteristics. Amphiboles collected on air monitoring filters from three mining sites where nonasbestiform amphiboles are major rock-forming minerals and two industrial sites employing commercial amphibole asbestos were characterized, and the data were statistically evaluated.

Airborne amphibole particles at mining and industrial sites are of interest to health scientists and regulatory agencies because of adverse health effects resulting from exposure to airborne amphibole asbestos [Selikoff and Hammond, 1979]. To regulate asbestos exposure in the occupational environment, air monitoring filtration techniques are used to determine the amount of asbestos suspended in the air. At present, federal regulations define chrysotile, amosite, crocidolite, tremolite, actinolite and anthophyllite particles as asbestos if they are $\geq 5 \mu\text{m}$ in length and $\leq 5 \mu\text{m}$ in width, possess straight sides, and have aspect ratios $\geq 3:1$ [OSHA 1975]. This definition does not distinguish between amphibole asbestos fibers and cleavage fragments of nonfibrous amphiboles [Campbell et al. 1977].

Siegrist and Wylie [1980] characterized the size and shape of amphibole particles in monomineralic bulk samples and compared their populations using the linear regression relationship:

$$\log_{10} \text{ width} = F \log_{10} \text{ length} + b \quad (1)$$

where F = slope of the regression line = fibrosity index, a measure of the dependence of width on length
 b = intercept on the log width axis

As shown by Wylie [1979], F may be used to distinguish amphibole cleavage fragments, the widths of which increase with increasing length, from amphibole asbestos fibers, which display relatively constant widths.

In the present study, the linear least-squares regression of log width vs log length is applied to amphibole particles collected on air monitoring filters

and compared with values obtained by Siegrist and Wylie [1980] on bulk samples. A potential application of this technique is the determination of an asbestiform or nonasbestiform source of amphiboles collected on air monitoring filters from various mining and industrial sites. As with any characterization technique, the results are only as good as the samples. Extrapolation from bulk mineral characterizations to classification of particles on air filters must be done with caution, since the assumption is not always valid that the source of the particles is either asbestos or nonasbestos. Particles from veins of asbestos can be present in air samples from operations in essentially nonasbestiform mineral deposits. In addition, sorting may occur in air currents and result in selective deposition of particles. For these two reasons, air monitoring filter samples may not be representative of a whole deposit.

SAMPLES

Air monitoring filters were obtained from the Mine Safety and Health Administration (MSHA) and the Occupational Safety and Health Administration (OSHA), from mining operations in amphibole-bearing rocks and from industrial sites employing asbestos, respectively. Mine selection was based on geology and mineralogy reported in the literature. The criteria used were the presence of amphiboles, the absence of minerals that were difficult to distinguish from amphiboles on the basis of chemistry and morphology, and the importance of the products—iron ore, gold and crushed stone. The type of mining or industrial operation and the amphibole(s) present at each site are listed in Table I.

SAMPLE PREPARATION

The industrial site filters were prepared by cutting 5- × 5-mm portions from the air monitoring filters as received from OSHA and mounting the sections with double-stick tape on SEM stubs. Latex spheres, 1.099 μm in diameter, were placed on each SEM stub for magnification calibration. The samples were carbon-coated in a vacuum evaporator before analysis. Samples were prepared in this manner because the long asbestiform particles are easily observed on the textured substrate of the collection filters.

Mining site filters contained very small particles that were difficult to observe on the textured filter. Therefore, portions of each filter were ashed in a low-temperature asher. The resulting ash was suspended in 10 ml distilled filtered water containing approximately 0.5 ml Aerosol OT dispersing agent, agitated ultrasonically for 5 minutes, and then filtered through a 0.1- μm Nuclepore filter. A 5- × 5-mm section of the Nuclepore filter was cut and mounted on a SEM stub. Latex spheres were placed on each SEM stub for

Table I. Type of Operation and Amphibole Present at Each Site

Type of Operation	Site	Amphibole(s)	Composition
Mining	Homestake Gold Mine, SD ^a	Cummingtonite	$(\text{Mg, Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$
Mining	Peter Mitchell Iron Mine, MN ^b	Cummingtonite, hornblende, actinolite	$(\text{Mg, Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$ $(\text{Ca, Na})_2(\text{Mg, Fe, Al})_5\text{Si}_8\text{O}_{22}(\text{OH, F})_2$ $\text{Ca}_2(\text{Mg, Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
Mining	Charlottesville Stone Quarry, VA ^c	Actinolite	$\text{Ca}_2(\text{Mg, Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
Industrial	Shipyard	Cummingtonite-grunerite asbestos (amosite)	$(\text{Mg, Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$
Industrial	Electric Company	Cummingtonite-grunerite asbestos (amosite)	$(\text{Mg, Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$

^aNoble [1950].^bGundersen and Schwartz [1962].^cGiannini and Rector [1958].

calibration of magnification, and the samples were carbon-coated. The Nuclepore filter substrate provided a smooth surface for observation of the very small particles present in these samples.

SAMPLE ANALYSIS

All samples were examined using SEM with EDS capability. The filters were scanned at 5000X, and particle measurements were made at 10,000X on the cathode ray screen of the SEM. When particles extended beyond the field of view, measurements were made at lower magnifications. A minimum of 250 particles with aspect ratio $\geq 2:1$ for the mining site samples and $\geq 3:1$ for the industrial site samples, straight sides, and suitable amphibole composition were measured. Most nonamphibole particles were eliminated by the use of the above criteria.

In all samples except those from the Peter Mitchell Mine, amphiboles could be distinguished from other minerals on the basis of particle morphology and chemistry (using EDS). In the Peter Mitchell samples, the pyroxenes hedenbergite $[(\text{Ca},\text{Fe})\text{Si}_2\text{O}_6]$ and hypersthene $[(\text{Mg},\text{Fe})_2\text{Si}_2\text{O}_6]$ could not be distinguished from hornblende and cummingtonite. However, pyroxenes are less abundant than amphiboles in the Peter Mitchell samples [Gundersen and Schwartz 1962] and should not represent a significant number of the particles measured. The length and width data for the amphiboles and pyroxenes on the Peter Mitchell Mine air filters were combined for the statistical analyses because of the similarities in their morphological characteristics.

Summary statistics including mean, minimum and maximum values were established for lengths and widths of each sample. Regression of the log width vs log length and standard error of estimate of log width based on log length were calculated for each particle population. The slope or "fibrosity index" of the regression equation was used to indicate the dependence of width on length for all samples. The summary statistics and aspect ratio distributions, commonly used to characterize particle size distributions, were used as the basis for evaluating the results of the regression analyses. These values were also compared with those obtained by Siegrist and Wylie [1980] on bulk mineral samples.

RESULTS

Particle Size Distribution

Results from the particle size distribution (Tables II and III) and regression analyses (Table IV and Figure 1) show two distinct sets of particle popula-

tions: one from the mining sites and one from the industrial sites. The particles from the mining sites are typically shorter and wider than those from the industrial sites. Length ranges for the particles from the mining sites are smaller than those from the industrial sites, while the ranges in widths are greater for the mining site particles.

Table II. Length and Width Characteristics of Airborne Amphibole Particles

Site	Number of Particles Counted	Length (μm)			Width (μm)		
		Mean	Min.	Max.	Mean	Min.	Max.
Mining							
Homestake Gold Mine	266	4.6	0.9	17.5	1.1	0.3	4.8
Peter Mitchell Iron Mine	464	5.5	1.0	32.4	1.2	0.2	5.0
Charlottesville Crushed Stone	605	5.3	0.8	36.0	1.4	0.2	12.0
Industrial							
Shipyard	698	8.2	0.9	93.5	0.4	0.1	2.6
Electric Company	285	15.6	1.3	181.0	0.5	0.1	1.7

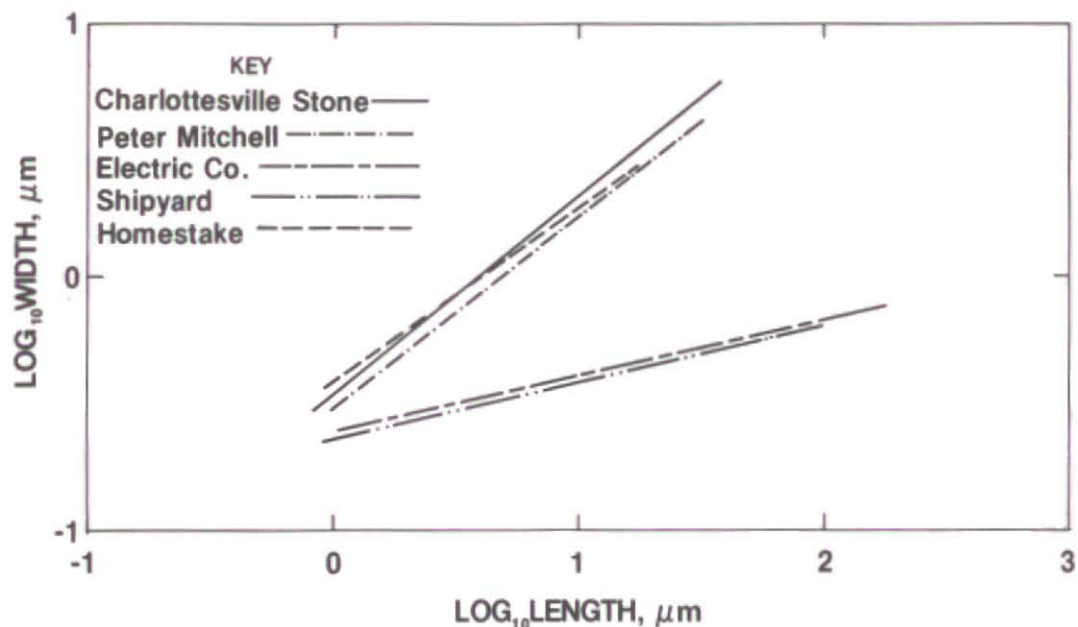


Figure 1. Regression lines summarizing length and width data collected for amphiboles on air monitoring filters from mining and industrial operations.

Table III. Comparison of Aspect Ratios for Airborne Amphibole Particles

Site	Distribution of Particles, (%) for Aspect Ratio							Total Number of Particles
	2:1 to 2.9:1	3:1 to 4.9:1	5:1 to 9.9:1	10:1 to 19.9:1	20:1 to 49.9:1	50:1 to 99.9:1	≥100:1	
Mining								
Homestake Gold Mine	22	46	28	4	0	0	0	265
Peter Mitchell Iron Mine	3	62	27	7	1	0	0	464
Charlottesville Crushed Stone	31	41	21	6	1	0	0	605
Industrial								
Shipyard	ND ^a	5	23	31	30	9	2	698
Electric Company	ND ^a	4	13	24	37	14	8	285

^aND = not determined.

Table IV. Fibrosity Index for Airborne Amphibole Particles

Site	Regression Analysis		Standard Error of Estimate
	Fibrosity Index (F)	Y Intercept (b)	
Mining			
Homestake Gold Mine	0.68	-0.43	0.17
Peter Mitchell Iron Mine	0.76	-0.52	0.18
Charlottesville Crushed Stone	0.78	-0.46	0.20
Industrial			
Shipyard	0.24	-0.64	0.26
Electric Company	0.21	-0.61	0.26

Aspect Ratio Distribution

The aspect ratio distributions (Table III) emphasize the significant differences between the mining and industrial site samples. The mining site populations have more particles in the lower-aspect-ratio categories than do the industrial site populations. Aspect ratios for 93% of the mining site particles are $\leq 10:1$, while only 25% of the industrial site particles are $\leq 10:1$. In terms of higher aspect ratios, only 1% of the mining site particles exceed 20:1 in aspect ratio, while >45% of the industrial site particles fall in this category. Long, thin amphibole particles (high aspect ratio) are the ones generally associated with adverse biological effects. These results for airborne particles are in general agreement with data on milled tremolite samples of various habits reported by Campbell et al. [1979].

Linear Regression Analysis

The linear least-squares regression of log width vs log length is another way of displaying the results described by the particle size and aspect ratio distributions (Table IV). The larger b values along with larger "fibrosity indices" indicate that the mining particles have greater widths than the industrial particles. The larger "fibrosity indices" for the mining samples also indicate a dependence of width on length, a characteristic typical of cleavage fragments [Siegrist and Wylie 1980]. In contrast to this, the low "fibrosity indices" of the industrial samples reflect the uniform width (independent of length) typical of asbestos fibers [Wylie 1979]. The fibrosity indices of each sample

were compared with those obtained by Siegrist and Wylie [1980] on bulk asbestos and nonasbestos amphibole samples (Table V). The fibrosity indices of the industrial site samples are similar to those obtained on bulk asbestos amphibole samples. The fibrosity indices of the mining sites are similar to those obtained on bulk nonasbestos amphibole samples.

Visual examination of the regression lines (Figure 1) provides a rapid morphological evaluation of the particle populations. The two distinct sets of particle populations described above can be easily seen. The mining site particle length range is smaller than the industrial site particle length range, and the industrial site particles have higher aspect ratios than do the mining site particles. The dependence of width on length and differences in particle widths for the five populations is also evident.

DISCUSSION

The differences in particle morphology can be attributed to the habits of the asbestos and nonasbestos amphiboles present in these samples. Asbestiform amphiboles, which are present in the industrial site samples, are composed of fibrils approximately 1000–1700 Å wide and up to several inches long. These fibrils can be easily separated from one another, but resist breakage across individual fibrils. Thus, long, thin, high-aspect-ratio particles are generated. Nonasbestiform amphiboles, like those present in the mining site samples, generally crystallize in a prismatic habit. These crystals have well-developed cleavage, which results in breakage both perpendicular and parallel to particle length. Consequently, short, prismatic, low-aspect-ratio cleavage fragments are produced as the particles are reduced in size.

Table V. Fibrosity Index for Bulk Amphibole Particles [Siegrist and Wylie 1980]

Sample	Regression Analysis		Standard Error of Estimate
	Fibrosity Index (F)	Y Intercept (b)	
Prismatic			
Tremolite	0.67	-0.19	0.18
Riebeckite	0.56	-0.34	0.34
Asbestiform			
Amosite	0.18	-0.56	0.20
Crocidolite	0.14	-0.71	0.19

CONCLUSIONS

Three main conclusions are drawn from the calculations of length, width and aspect ratio distributions:

1. The three mining sites have similar particle populations.
2. The two industrial sites have similar particle populations.
3. The mining sample populations can be distinguished qualitatively from the industrial sample populations.

These conclusions are similar to the results obtained from linear regression analyses. Based on the fibrosity indices, the analyses indicate morphological similarities among the industrial site particle populations and among the mining site particle populations. The industrial site particle populations are different from the mining site particle populations. Correlation between fibrosity indices of airborne and bulk amphibole samples suggests that fibrosity indices can be used to determine whether an airborne amphibole population is from an asbestos or a nonasbestos source. Thus, the linear least-squares regression technique is suitable for quantitatively describing the morphology of particle populations as well as aiding in the identification of a predominantly asbestiform or nonasbestiform amphibole source for the airborne amphibole particles.

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